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As the wireless communications industry in the U.S. stands poised for an explosion of new commercial and military applications(e.g. the Radio Mall, the Airlink), reducing the high cost of phased array antennas becomes ever more important. Reducing these antenna costs is the primary objective of this research. We will describe an effort that to date has produced a working prototype of a micropatch antenna incorporating a single dollar per bit phase shifter. Since 1987, when we have been involved in designing antenna systems using micropatch elements, early work led to our discovery of the Smart Electromagnetic Structure concept which resulted in the development of a neural controlled, frequency agile antenna element capable of following the frequency of incoming radiation, and tuning the antenna center frequency to that of the incoming signal. This can be applied to systems like frequency-hop radios. In this paper we will describe a method of controlling a micropatch antenna to provide phase only variation of the antenna characteristics using a similar device to that used for the frequency control experiments. We have successfully varied the phase of the antenna element without significantly changing the operating frequency. This work has led us to pursue further the design and fabrication of an array of such phase adjustable element to test the hypothesis that such phase controlled micropatch elements can be used to fabricate a low cost phased array antenna.

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Phase and Amplitude Controlled Micropatch Antenna

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Abstract

As the wireless communications industry in the U.S. stands poised for an explosion of new commercial and military applications(e.g. the Radio Mall, the Airlink), reducing the high cost of phased array antennas becomes ever more important. Reducing these antenna costs is the primary objective of this research. We will describe an effort that to date has produced a working prototype of a micropatch antenna incorporating a single dollar per bit phase shifter. Since 1987, when we have been involved in designing antenna systems using micropatch elements. Early work led to our discovery of the Smart Electromagnetic Structure concept which resulted in the development of a neural controlled, frequency agile antenna element based on micropatch technology. We have successfully demonstrated a frequency agile antenna element capable of following the frequency of incoming radiation and tuning the antenna center frequency to that of the incoming signal. This can be applied to systems like frequency-hop radios. In this paper we will describe a method of controlling a micropatch antenna to provide phase only variation of the antenna characteristics using a similar device to that used for the frequency control experiments. We have successfully varied the phase of the antenna element without significantly changing the operating frequency. This work has led us to pursue further the design and fabrication of an array of such phase adjustable element to test the hypothesis that such phase controlled micropatch elements can be used to fabricate a low cost phased array antenna.

Micropatch Antenna Background

The micropatch antenna(MPA) has been the mainstay of conformal antennas for many years. The antenna has many advantages including simplicity and size. MPA's are currently used in aircraft for communications and navigation. The automobile industry has been interested in MPA's for a number of years for the " no show antenna", and very recently the pager industry has become interested in a small conformal patch or array of patches for their miniature pagers. Very Small Aperture Terminal(VSAT) technology has brought about another opportunity for patches and arrays as the total size of the array is now within a inexpensively manufacturable size limit (if the effects of manufacturing tolerances and variability of element placement can be reduced, and if an inexpensive phase shifting array can be developed the micropatch array could be used).

• Implications of a Neural Controllable Patch Antenna

The electrical characteristics of the Controllable MPA(CMPA) can be adjusted using impedance elements embedded in the patch itself. We have used these techniques in the control of microstrip patch antenna elements using a neural network (NN) in the feed back loop to automatically adjust the operating frequency of the antenna. The neural net can be taught by example, rather than requiring the calculation of new control points for each new condition as in an algorithmically controlled array. The ability of the net to adapt to previously unknown inputs (generalization) and its fault tolerance makes the neural antenna an ideal candidate for flexible tactical antennas for the future.

The antenna could be manufactured with a set of control devices placed at convenient points on the patch surface. The network could then determine the configuration of these points necessary to achieve the desired tuning effect after manufacture thus reducing the effect of manufacturing tolerance on the performance of the antenna.

We have demonstrated that the control elements can be used to eliminate the effects of manufacturing dimension variations(i.e. a length error of 0.0005 inches will result in the antenna operating at a frequency outside of the desired operating bandwidth, with the control element embedded in the antenna we can adjust the operating frequency to that of the design goal with the correct impedance characteristics.

• Commercial Future of MPAs

Micropatch antennas and arrays show great promise in several commercial as well as military applications. The applications of a neural phased array of patches like the one being developed in our lab can be applied to a number of current and future technologies. Several are described below.

An immediate application of the tunable MPA is in the Air Link concept currently being proposed for the commercial airline industry. This system would employ MPA's for the collection and transmission of data, voice and video via satellite for the use of the crew and for sale to the passengers. This system will eventually be installed in all commercial aircraft.

Today some recreational vehicles are equipped with a satellite television receiver operating in the microwave frequency range. The dish antenna is mechanically steered and is cumbersome, offers wind drag and requires set up when the vehicle has stopped, and the users wish to view television. A conformal array covering the roof of the motor-home would provide a steerable array with equivalent or better beam size. The main consideration inhibiting their application in this industry is the cost of the steering components and the manufacturability of the antenna elements. The neural tunable array as proposed here could solve this problem, thus opening up a larger number of private and commercial vehicles for access to a satellite systems.

Another application would use a neural array of controlled MPA's for the VSAT system. The ability to install such an antenna on the roof of a building without altering the shape or look of the roof could make the already desirable characteristics of the VSAT concept very appealing where the esthetics of buildings is a required aspect of the building code.

Global Positioning System already uses the micropatch technology for its antennas. The additional flexibility of the CMPA could reduce the cost of the antenna system even more and make it more resistant to physical damage. The use of frequency shifted signals in the GPS satellite frequency range(1500MHz, and 1200MHz.) as proposed for flexibility can be accomplished by a CMPA also.

- **Ease of Manufacture**

The controlled micropatch antenna is inherently easier to manufacture than a standard micropatch antenna because the ability to adjust the characteristics of the antenna after manufacture thus allowing the user to compensate for changes in performance caused by manufacturing variations after the fact. The control element is a common varactor and requires no special handling. The insertion point is just a through-post between the antenna element and the ground plane or a ground guard ring on the ground plane. This can be produced by normal printed circuit techniques.

- **Cost**

The cost of the modification is minimal, a mask change for the etching mask to include the tuning point , and on the reverse side(ground plane) the addition of a guard ring for the control element. The cost of the control element is only a few cents per element. A ferrite bead is used to isolate the DC control voltage from the bias supply. If the bias were supplied by a microstrip feed circuit a suitable choke element could be added. Instead of $400,for an eight bit phase shifters (where phase is limited by input quantization). We estimate our analog phase shifter (only limited by the digital driving circuit) to be in the single digit dollar range or less.

- **Our Neural Controllable Patch(Frequency Control)**

The control of the frequency of microstrip patch antennas has been described by several authors [Long,1987, Richards 1985]. Thursby et al. have reduced this to practice by developing a closed loop neural processor controlled micropatch antenna that has the capability to adjust its center frequency to the frequency of incoming radiation. This capability can be used to compensate for manufacturing variations, various siting conditions and for damage to the antenna element. It was hypothesized that the same mechanism could be used in principle to control the phase shift of the radiated signal. The development of this hypothesis and its initial verification were the subject of the first grant provided by the Air Force Office of Scientific Research(F49620-93-1-0286). The funding of our new proposal will allow us to refine this concept and produce a device(a phased array antenna using the phase controlled antenna element) to further define the capabilities of the controllable patch.

Review of neural controlled antenna elements(History.)

The integration of an artificial neural network(ANN) with a tunable conformal antenna was proposed by our group. Funding provided by an Army Research Office URI Grant allowed us to explore this synergy for three years. The closed loop control of the frequency of a microstrip patch antenna has been demonstrated. We have established the baseline for research in this area. We were the first university publishing work in this area in the U.S. and our work is currently several years ahead of the only other work published[Purchine et al. 1993]. We believe that ours is a unique program offering great potential for payoff.

We have designed a neural network controlled antenna with the ability to tune automatically to the center frequency of a received signal. Because of its self adaptability the

closed loop neural control of an antenna element, provides the potential for design of an easily produceable antenna which is immune to typical siting problems, and is tolerant to moderate external damage. The use of a neural processor in such a system provides very fast response times, especially when the system is implemented in its native parallel architecture.

Our first goal in training the smart antenna structure was to provide high speed frequency tracking of an unknown incoming signal. The system is composed of tunable antenna, a neural network controller and receiver. The closed loop antenna element is trained to optimize the antenna function within the system.

The network consists of four layers, fourteen neurons in the input layer and twenty in the second layer. There is one neuron in the penultimate layer and one linear neuron with fixed weights and an integrating connection in the output. Two neurons in the input layer receive sensor information from the receiver, the rest of the input layer neurons receive delayed values in a shift register fashion from their neighbor. There are a total of seven pairs of neurons in the input layer. For training, a modified back-propagation algorithm was used. Since the input layer has time-delayed input values, we wait to change the weights until all input neurons have received an input from a given test pattern.

The neural network was trained with a conventional back-propagation(BP) algorithm. The basic BP algorithm was modified to include a strategy for choosing the input training patterns and for calculating the error terms. Input values for the neural network came from the receiver(I,Q). The target value were determined at the output of the neural network. Target values were determined by subtracting accumulated voltage from the desired target voltage. The neural antenna is able to tune its center frequency in response to step frequency changes, random step sequences of frequencies and linear velocity changes in incoming signal frequency. Thus it is well suited to receiving frequency hop spread spectrum signals as well as chirped signals.

Results

We set out to determine the phase shifting capabilities of a control element in a micro patch antenna. We hypothesized that as a first approximation our basic tuning element could be used with modification.

We began by placing two varactors at control locations similar to the location of one control element used in the earlier study. Figure 1 shows the response of the reflection S-Parameter S_{11} to the variation in control voltage of both the control elements. As can be seen from the diagram the resonant frequency of the patch is altered by both control voltages. In this configuration the twc control diodes are being excited with respect to the ground plane. Figure 2 shows the configuration of the two control elements. We then proceeded to determine the effect on signal phase of the bias system. This was done by measuring the impedance phase for the antenna, while varying the bias on the control devices. The dependence of the phase with respect to the frequency of operation was determined. We have studied the insertion of two parallel devices to determine their effect on the phase and frequency of the operating antenna.

The use of two symmetrical elements was decided upon as the system on which we would conduct further tests. Figure 2 shows the physical layout of the two antenna control elements, their associated guard rings and the feed structure for the control elements. We studied the effects and interaction of one control element on the other and their effect on the antennas operating characteristics.

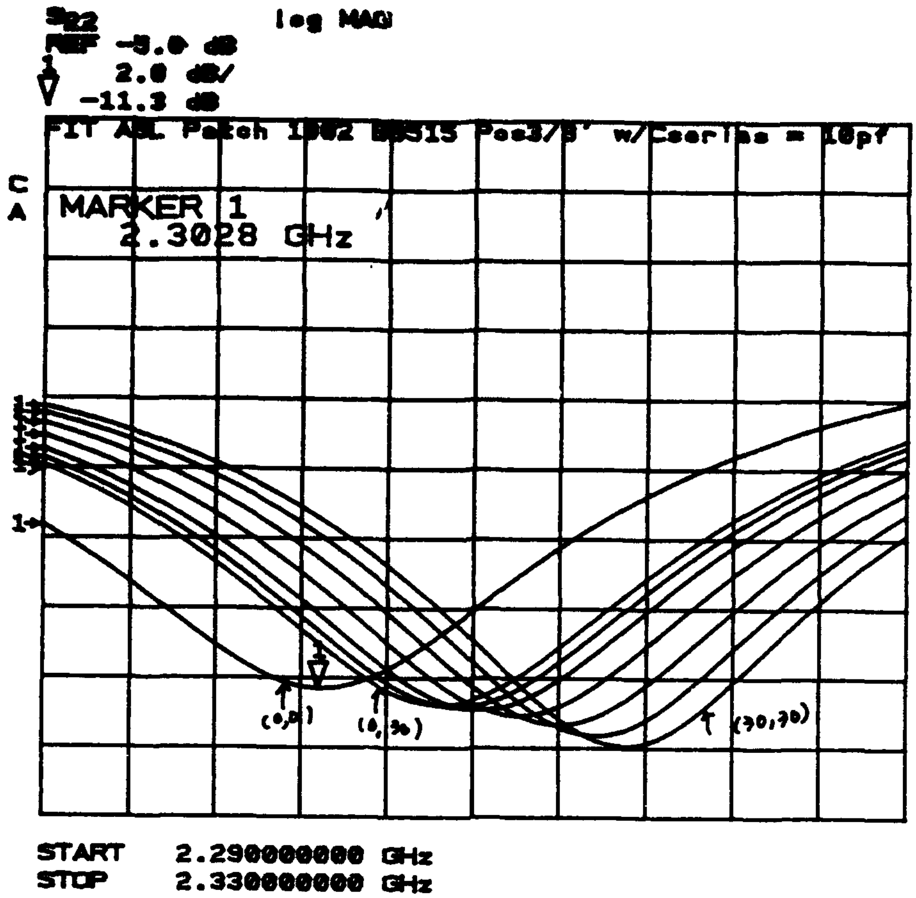

Figure 1 Measured S_{11} for the controlled antenna with the control element voltage refrence to the ground plane.

<u>Our Preliminary Work on the Phase Controlled Antenna</u>

Effects of Series Capacitance between the guard-ring and ground on the phase and frequency control of the micropatch antenna.

It was discovered that by adding a series capacitance between the guard ring and the actual ground plane the effects of the control element could be varied drastically. With one configuration, the use of a series capacitance between the guard ring and ground, the varactor provided similar results to those observed in our single varactor work (i.e. we can vary the value of the patch resonant frequency.)

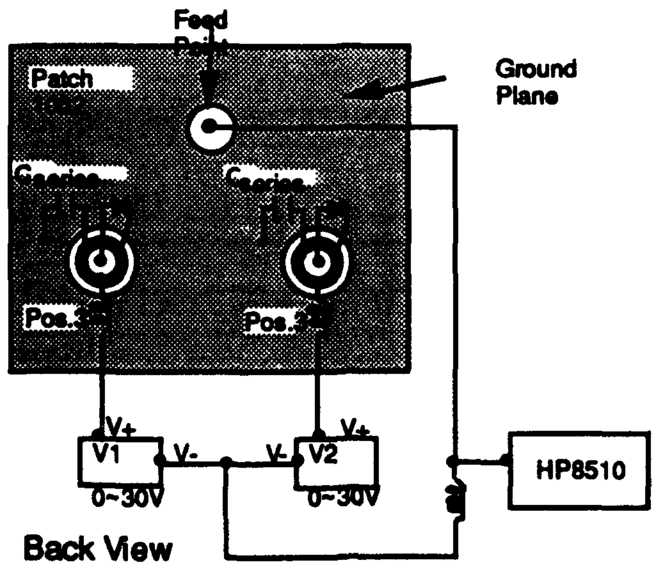

Figure 2 Shows a schematic representation of the feed structure for the phase controlled

of operation as did the earlier model of MPA with control element. When the guard ring was not capacitively coupled to the ground plane the antenna exhibited a response of changing the impedance phase angle of the antenna without appreciably changing the resonant frequency.

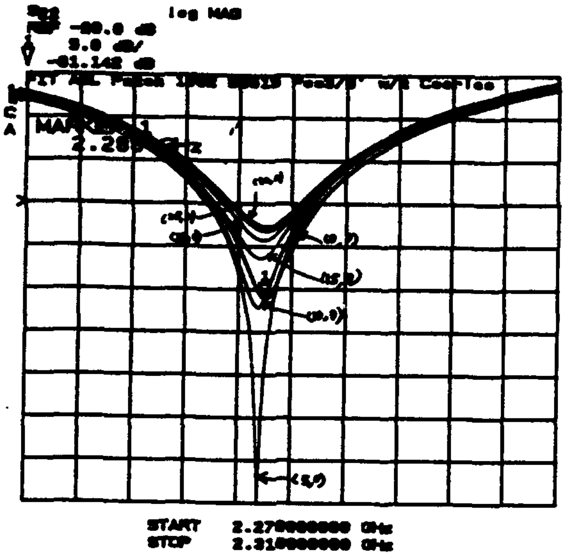

Figure 3 S_{11} center frequency for the control antenna. The control element is coupled through the guard ring to the ground plane.

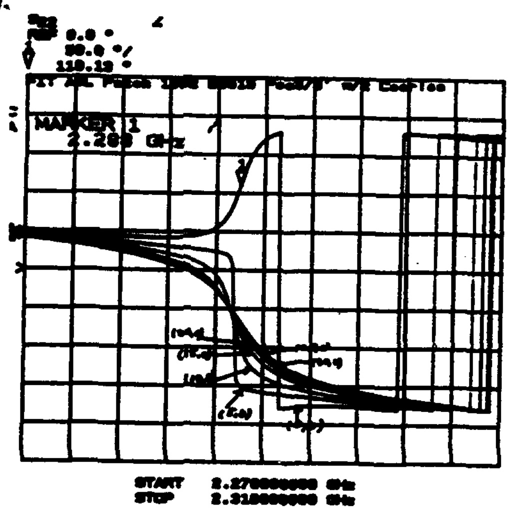

Figure 4 S_{11} Phase for the controlled antenna with the control element coupled through the guard ring to the ground plane.

Figure 3 shows that with one control element coupled to the ground plane through the guard ring the center frequency is nearly fixed while the bias voltage is varied from 0 Volts to 30 Volts. Figure 4 shows the variation of impedance phase with the same bias voltage change.

There were two regions of control exhibited by the device used. From zero to five volts of control voltage the patch showed rapid phase change with control voltage, as shown in Figure 5 where the control voltage versus phase shift is shown. In the second region from a few volts bias to thirty volts bias the phase of the antenna changes but so does the center frequency. We believe that the first region is the one of interest, and should be investigated further.

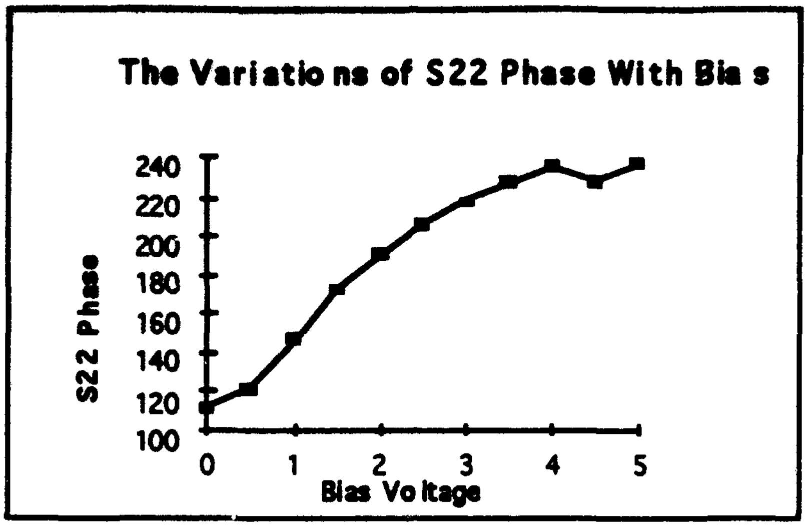

Figure 5 The phase shift of the antenna varies nearly linearly over the range of 0 to 5 volts.

Conclusions

The dual controlled micropatch antenna using a guard ring to couple the control element to the ground plane seems to provide a phase controlled antenna element that is potentially very inexpensive, stable and adaptable to various external conditions. We are currently studying the phase control capabilities of the elements while varying the location and circuit characteristics of the control elements.

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